Muon Acceleration

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Muon Accelerator Program Review
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Muon Acceleration Goals & Parameters

	ν factory	μ collider
p_i (MeV/c)	220	?
p_f (GeV/c)	25	750
$\varepsilon_{n\perp}$ (μm)	6000	25
$\varepsilon_{n\parallel}$ (mm)	25	70
Repetition rate	50	15
Trains/pulse	3	1
Muons/train	4×10^{11}	2×10^{12}
Bunches/train	≈ 23	1

Primary Design Goal Hardware Efficiency

- Linac to 750 GeV would be expensive
  - Much (all for ν factory) would be low frequency
- Re-use RF systems: multiple passes
  - Cost inversely proportional to passes
- Arcs needed to return beam to RF
  - Cost depends on type of system
- Use different types of accelerators for different energies
  - Choose most efficient type
  - More efficient types won't work (or will be less efficient) at lower energies

Types of Accelerators

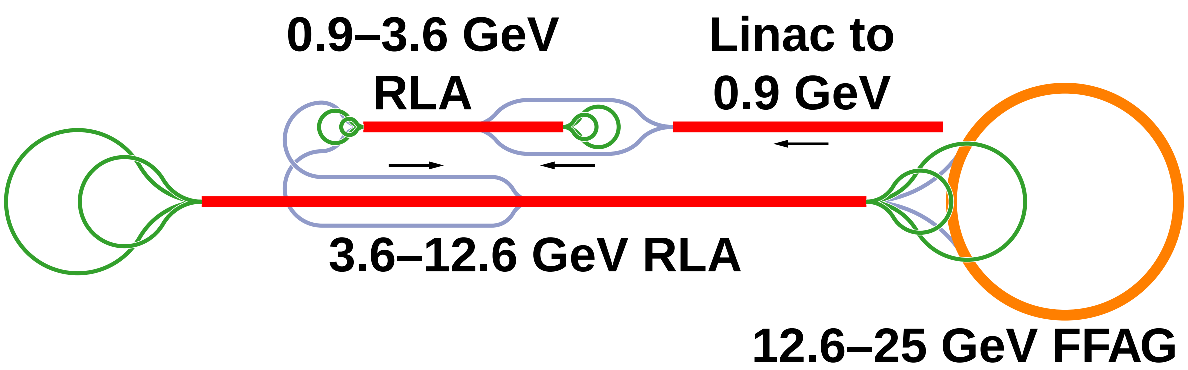
- Linac: single pass
  - Other systems won't work at lowest energies
- Recirculating linear accelerator
  - Separate arc for each pass (different energies)
  - Number of passes limited
    - Switchyard complexity, beam overlaps between passes
    - Matching linac to every energy
  - Most conventional system for multiple passes

Types of Accelerators

- Ramped synchrotron
  - Ramp magnet fields with beam momentum
  - Rapid acceleration (avoid decays): fast ramping
  - Will only work at highest energies
  - Arbitrary number of passes: efficient
- Fixed Field Alternating Gradient (FFAG)
  - Single arc for full energy range
    - Avoids switchyard from RLA: more passes
    - Large aperture: expensive
  - Fixed fields: avoid ramping
    - Usable at lower energies
  - Inefficient at very low energies

Neutrino Factory

- Well-defined acceleration scenario
  - Linac to 0.9 GeV: RLA won't work at lower energies
    - Velocity variation in linac
    - Energy spread and beam size at switchyard
  - Two 4.5-pass "dogbone" RLAs to 3.6 and 12.6 GeV
  - FFAG to 25 GeV: 12.5 turns
    - Less efficient at lower energies
    - Large transverse emittance creates difficulties



Neutrino Factory R&D Goals

- Finalize injection/extraction design for FFAG
  - Kickers and septa very challenging
  - May affect final FFAG lattice parameters
- Full system simulation with realistic magnet fields
- Verify that FFAG is more cost-effective than RLA
  - Rough relative costing, from scaling up RLA design
- High gradient in 200 MHz superconducting RF

Muon Collider Power Efficiency

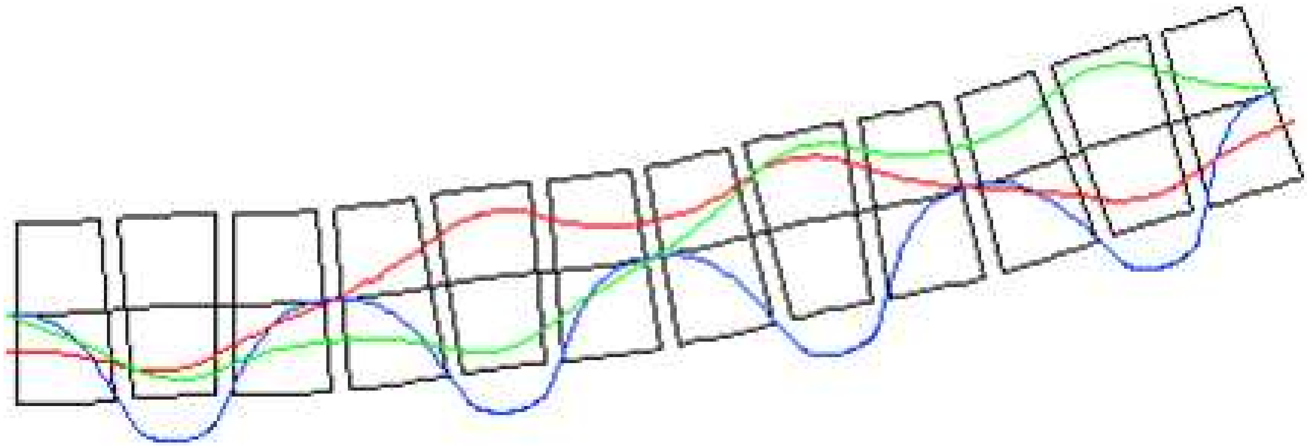
- 7 MW of muon beam power at end
- Power efficiency

$$\frac{\text{Energy delivered to beam}}{\text{RF energy delivered to cavity}}$$

- Low efficiency, high RF power requirements
- Efficiency depends on product of
  - Fractional energy extraction per bunch (train)
    - Larger at higher frequency
    - Larger with higher charge
  - Number of turns (like hardware efficiency)
- Product ideally about 4 (≈24 turns at 1.3 GHz)

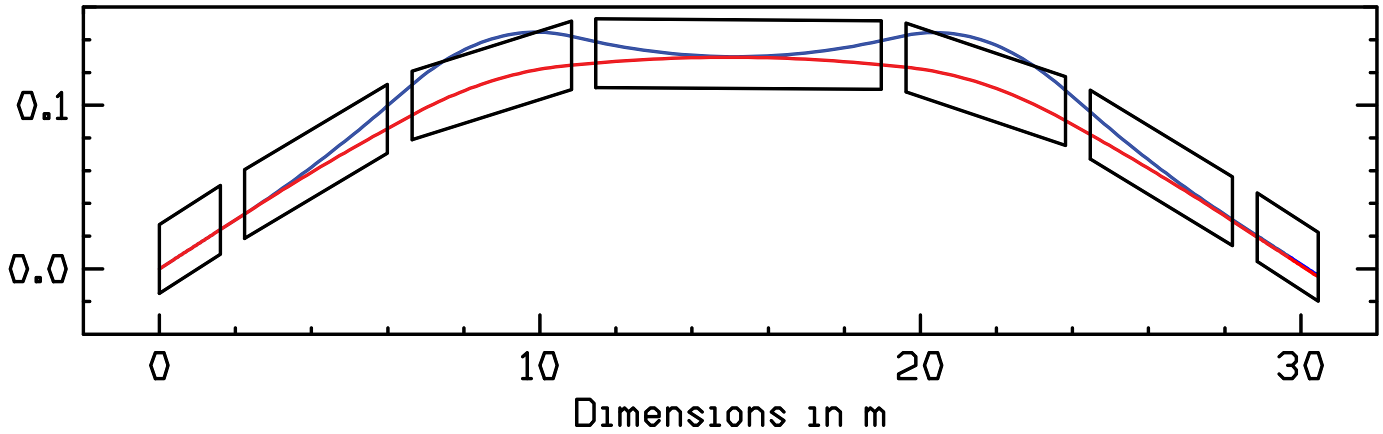
High Energy Acceleration RLA

- RLA most straightforward solution
- Limited number of passes
- Solutions to increase passes
  - Ramp linac magnets: stronger focusing, better matching
  - Use multiple FFAG arcs: $>$ 1 pass per arc



High Energy Acceleration
Fast Ramping Synchrotron

- High energy: more time ($\sim$1 ms) to ramp magnets and top off RF
- Keep average field high: mix
  - Fixed-field superconducting dipoles
  - Ramped (-1.8 T to $+1.8$ T) warm dipoles
- Closed orbit changes during acceleration



High Energy Acceleration Fast Ramping Synchrotron

- Lattice design need to be optimized
  - Time of flight constant (RF synchronization)
  - Tunes constant
  - Minimize orbit variation
    - Smaller aperture, smaller power supply
- Chromatic correction
- Determine best way to insert RF
  - More RF sections better
    - Higher synchrotron tune, collective instability suppression
  - RF/drift in each cell
  - Dispersion suppressed sections
    - Suppress orbit variation also

Collective Effects

- Beam loading w/ high current
  - ≈8.3% energy extraction per pass for 1.3 GHz
- Large additional contribution from HOMs, etc.
- Small vacuum chamber in ramped magnets
- Mitigation
  - Lower frequency RF
  - Strong synchrotron oscillations
    - Distribute RF around ring: arc/ring act like mini-ring
    - Mode coupling viewpoint: higher ν_s separates modes
  - Chromaticity
  - Few turns, growth tolerable?

Muon Collider Acceleration Intermediate-Energy Stages

- Start similar to neutrino factory
- Intermediate stages depend on high-energy choice
- Possible options
  - Non-scaling FFAGs
    - Work very well with smaller transverse emittance
    - Very efficient at high energy
    - Many turns possible
    - No synchrotron oscillations
  - Non-hybrid fast ramping synchrotron
  - RLA fallback solution

High Energy Acceleration R&D Goals

- Design lattice for highest energy stage
  - RLA solution (with and without ramping)
  - Fast ramping solution
- Understand limits/costs of ramping magnets and power supplies
- Add intermediate stages for these solutions
- Study high charge/impedance collective effects
- Compare performance/cost of solutions, choose initial configuration

Planning in First Years Simulations

FY11 ν factory: Simulations, final details of initial configuration
Lattices for μ collider high energy stages
Basic collective effects studies

FY12 Finalize μ collider high energy designs
μ collider designs: all stages
Single stage simulations with collective

FY13 Full μ collider system simulations
Choose μ collider initial configuration

Summary

- ν factory design essentially settled
  - Need to know 200 MHz SCRF capabilities
  - Verify FFAG cost advantage
- μ collider must select design
  - Highest energy: fast ramping synchrotron favored
    - Hardware and power efficiency
    - Collective effect stabilization
    - Verify ramping magnets feasible and cost effective
  - RLA should be a feasible fallback
    - May be more difficult to handle collective effects
  - Intermediate energy systems to be chosen
    - Depends partially on high energy system